AD-A086 046 FEDERAL AVIATION ADMINISTRATION WASHINGTON DC OFFICE--ETC F/6 1/2
ACTIVE BCAS PERFORMANCE IN A GARBLE ENVIRONMENT.(U)
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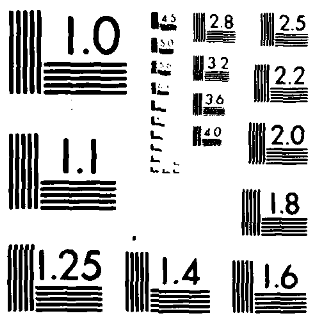

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ACTIVE BCAS PERFORMANCE IN A GARBLE ENVIRONMENT

JANUARY 1980

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FEDERAL AVIATION ADMINISTRATION
OFFICE OF SYSTEMS ENGINEERING MANAGEMENT
Washington, D.C. 20591

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-EM-80-1	AD-A086 046	11 24 JAN 80

4. Title and Subtitle	5. Report Date
6 Active BCAS Performance in a Garble Environment.	Jan. 24, 1980 12 50
	6. Performing Organization Code AEM-200
7. Author(s) 10 Dr. Edmund J. Koenke	8. Performing Organization Report No. 14 FAA-EM-80-1
9. Performing Organization Name and Address Federal Aviation Administration Office of Systems Engineering Management 800 Independence Avenue, S.W. Washington, D.C. 20591	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Same as above.	13. Type of Report and Period Covered 14. Sponsoring Agency Code AEM

15. Supplementary Notes

16. Abstract

A basic design tool has been developed which includes the principal BCAS design parameters, namely, transmitter power, receiver sensitivity, aircraft density, closure rate, degarble capability, and interrogation rate. This tool can be directly applied to the evaluation of alternative BCAS design concepts as well as for parametric design studies. Results of a comparison between an ATCRBS/DABS BCAS and an ATCRBS only BCAS are presented leaving little doubt concerning the performance advantage offered by the inclusion of the DABS link for evasive maneuver coordination. It must be emphasized that neither of the BCAS systems analyzed in this report are representative of the active BCAS defined in the draft National Standard for active BCAS.

17. Key Words	18. Distribution Statement
BCAS, Active BCAS, Garble, Collision Avoidance, Threat Acquisition, Data Link	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLAS	UNCLAS		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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ACKNOWLEDGMENT

The author wishes to thank Mr. Del Weathers and Ms. Sandy Boczenowski for their support in the development of the computer simulations used to obtain the results presented as part of this report.

ACTIVE BCAS PERFORMANCE ANALYSIS

INTRODUCTION

In the design of an active BCAS, there are many parameters which affect its capability to detect targets. Target detection is obviously critical to BCAS performance since without detection, all other considerations such as tracking accuracy, threat detection and resolution strategy and evasive maneuver coordination become secondary. This report presents a method of estimating BCAS ability to detect targets as a function of aircraft density, closing speed, RF power and receiver sensitivity, the ability to degarble overlapping replies, interrogation rate and the time at which coordination and execution of evasive maneuvers is to occur. Application of this analysis to the evaluation of the effectiveness of a Mode A data link for evasive maneuver coordination is also presented.

APPROACH

A fairly straight forward analysis based on the use of the Binomial Theorem coupled with a Monte-Carlo simulation has been applied to evaluate BCAS performance.

It is best to begin discussing this analysis by reviewing the active BCAS garble phenomenon. When an active BCAS interrogates either on Mode A or Mode C, it is assumed for purposes of this analysis that the interrogation travels uniformly in space at the speed of light. Aircraft receiving the BCAS interrogation reply in the appropriate format. Since this reply is 20.3 us long, when two aircraft are within a range of 1/2 the reply distance (about 1.69 nautical miles) their replies will overlap each other when they arrive at the BCAS aircraft. (See Figure 1)

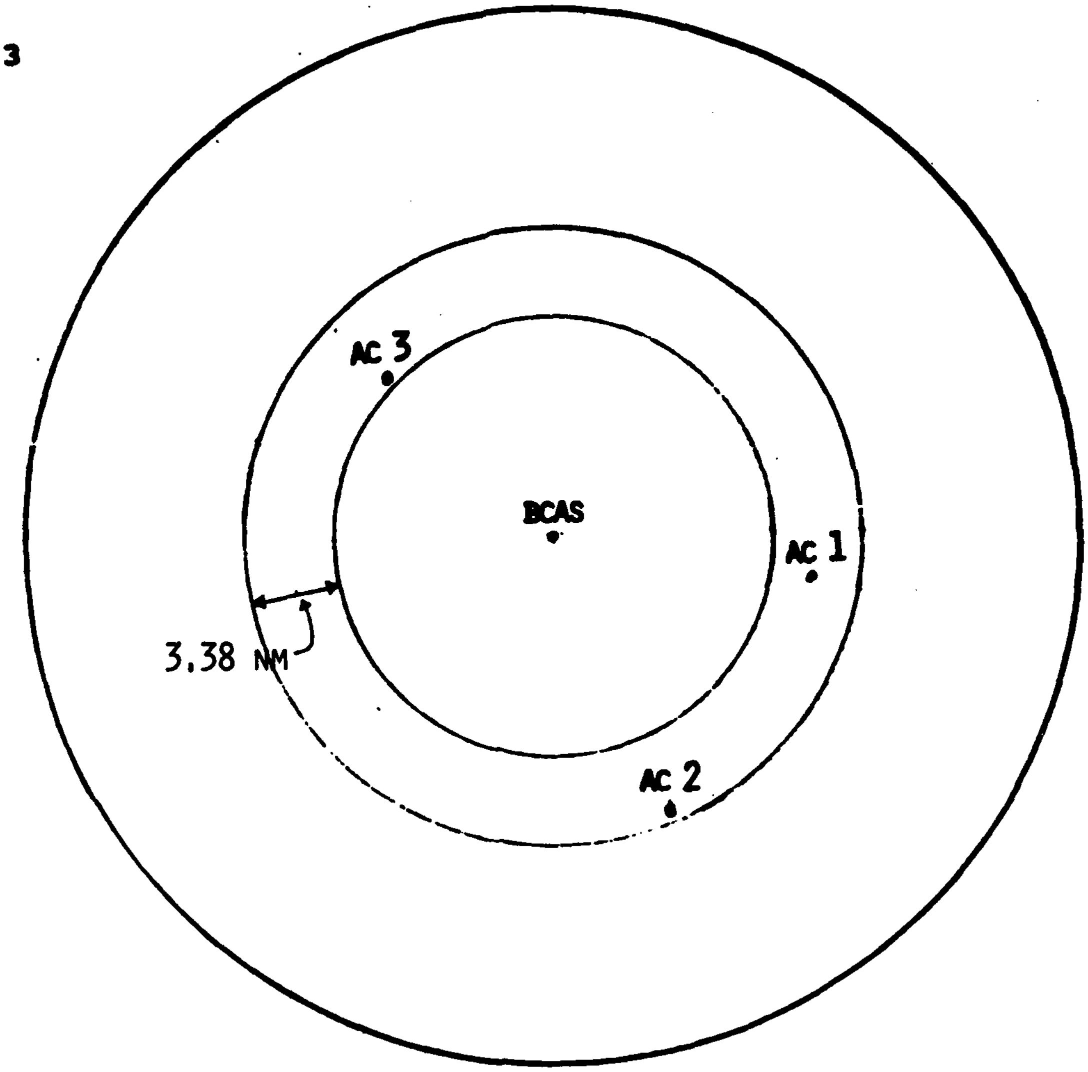

FIGURE 1. ACTIVE BCAS GARBLE PHENOMENON

As seen in Figure 1, the replies of AC #1 and #2 and of #1 and #3 will arrive overlapped at BCAS. Replies of #2 and #3 will not overlap since their range difference is greater than 1/2 the reply distance (1.69 nm).

In order for these replies to overlap at BCAS, two criteria must be satisfied. First, the aircraft must be within the specified range differential from BCAS and second they must hear the BCAS interrogation, reply to it, and BCAS must hear the reply.

The probability that an aircraft will be within an annulus of thickness of $2\Delta r$ centered at a distance r from the center of a circle of radius R (see Figure 2) is given by:

$$p_E = \frac{(r + \Delta r)^2 - (r - \Delta r)^2}{R^2}$$

or more simply by:

$$p_E = \frac{4\Delta r \cdot r}{R^2} \tag{1}$$

where it is assumed that it is equally likely that the aircraft is at any point in the circle.

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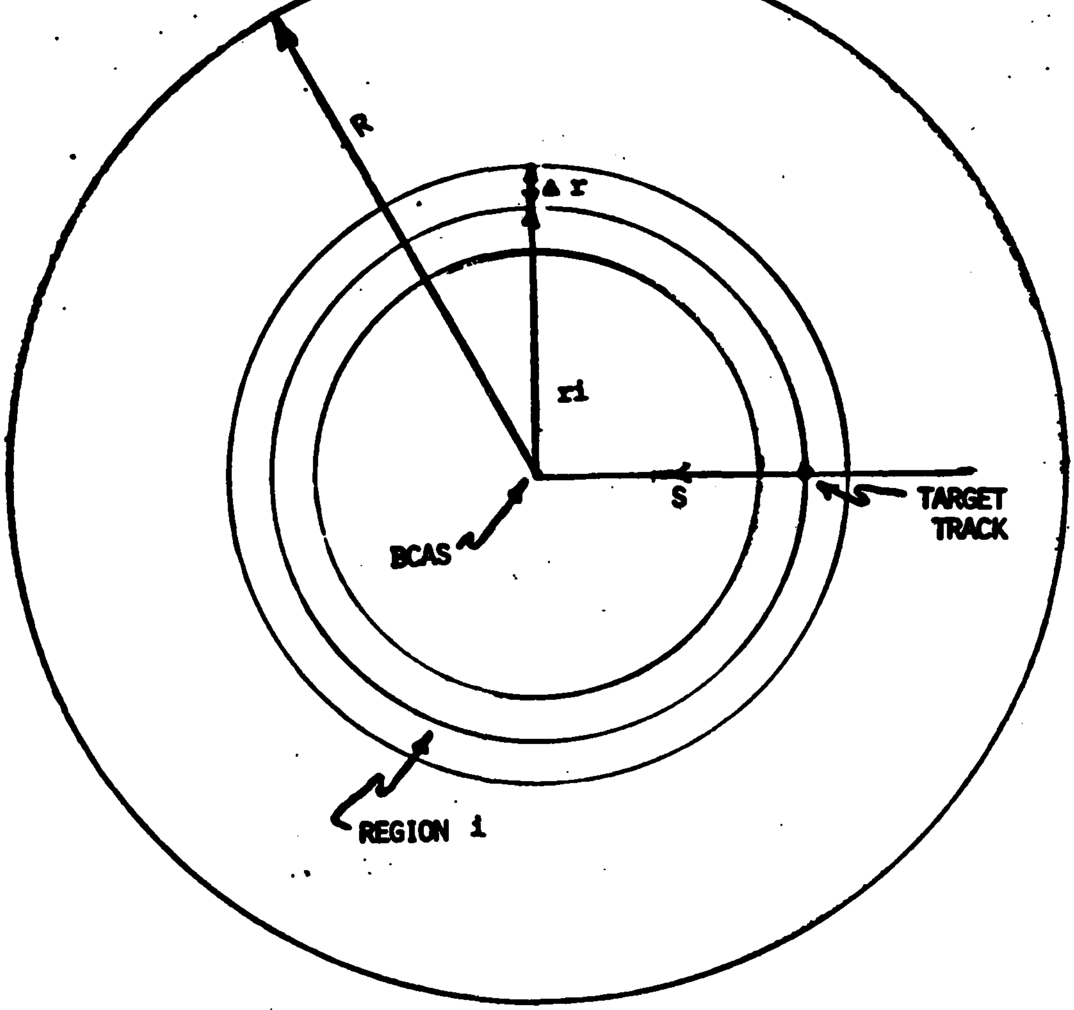

FIGURE 2

BCAS PROBABILITY MODEL

The probability that BCAS will "see" an aircraft located at a distance r from BCAS has been derived in Reference 1 and basically is a function of range, transmitter power and receiver sensitivity which are used to compute the link margin.

In Reference 1, the computation of link margin is described as is the relationship of link margin and link reliability. This relationship is presented as Figure 3.

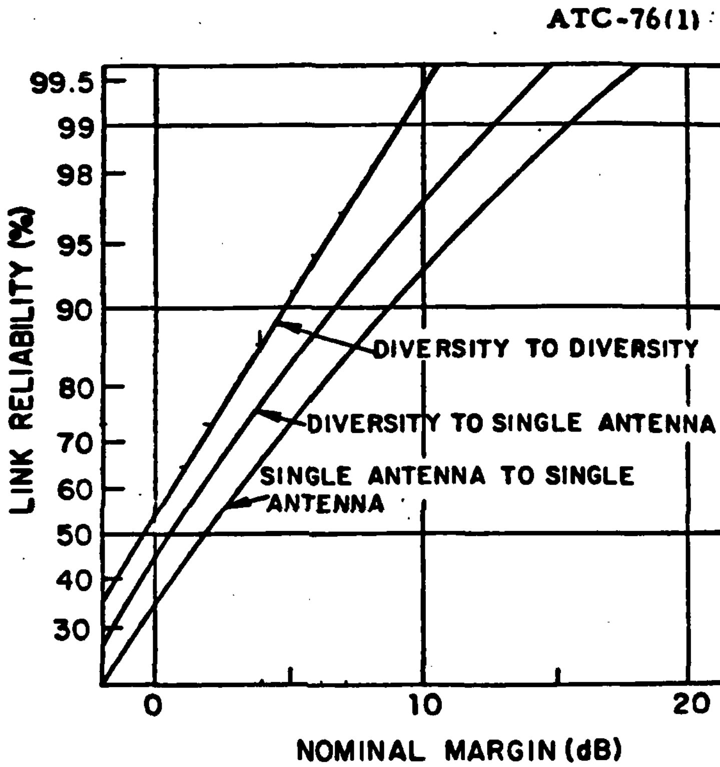

FIGURE 3

RF POWER AND SENSITIVITY EFFECTS

Let the link reliability be denoted by p_L . Then, the probability p that an aircraft lies in the annulus (see Figure 2) and will be "seen" by BCAS is given by:

$$p = p_E \cdot p_L \tag{2}$$

The probability p is computed as a function of free space path loss, receiver sensitivity, interrogator power and cabling losses. This is accomplished first by computing the normal link margin and then using the appropriate curve from Figure 3.

With this basic probability, it is now possible to derive the probability that a threat aircraft located at a distance r from BCAS in an airspace with N other aircraft uniformly distributed over the area of a circle of radius R will be "seen" by the BCAS aircraft located at the center of the circle.

This probability is directly computed using the Binomial Theorem which yields the probability that exactly k aircraft will be region i (See Figure 2) and be seen by BCAS.

This probability is given by:

$$P_k = \binom{N}{k} p^k (1 - p)^{N-k} \tag{3}$$

where p is calculated from equation 2 and where:

$$\binom{N}{k} = \frac{N!}{k!\,(N-k)!} \tag{4}$$

Now, to treat the effect of garble, assume that one overlap of the threat aircraft's reply to BCAS can be degarbled with a probability g_1 and that two overlaps of the threat aircraft's reply to BCAS can be degarbled with a probability g_2. Further, assume that it is impossible to degarble more than 2 overlaps of the threat aircraft's reply to BCAS. This being the case, the probability that BCAS will successfully "see" the threat aircraft is given by:

$$P = p_L \left[(1-p)^N + Np\,(1-p)^{N-1} g_1 + \frac{N\,(N-1)}{2} p^2 (1-p)^{N-2} g_2 \right] \tag{5}$$

In equation 5, note that p is a function of the distance of the threat aircraft from BCAS.

Next, consider that the target aircraft is moving toward BCAS in relative motion. To compute the probability P in equation 5 as the target moves toward BCAS, consider the threat aircraft range from BCAS as a function of time t and closing speed w. Assuming rectilinear motion, this relationship is given by:

$$r = wt$$

so that for constant closing speed and specified times t_i the probability that BCAS will successfully see the threat aircraft at time t_i is computed from:

$$r_i = w\, t_i$$

and

$$p_i = p\,(r_i)$$

and

$$P_i = P\,(p_i) \tag{6}$$

Equation (6) in effect causes the annulus to move with the target as it approaches the BCAS aircraft thus changing the probability P_i as a function of time.

Thus, given t_i , closing speed w , number of aircraft N, radius R, link reliability p_L (also a function of range), degarble capability g_1 and g_2 and reply message length it is possible to compute the probability P_i that BCAS will "see" the threat aircraft in region i .

THREAT ACQUISITION PROBABILITY

In general, active BCAS systems acquire ATCRBS targets by interrogating on Mode C at a regular interval Δt . This time interval is called a BCAS epoch. For successful target acquisition, track initiation and threat detection assume that it is necessary to successfully "see" a target L out of M tries. To compute this probability of successful acquisition, one is tempted to again use the Binomial Theorem but in equation 6 one notes that the probability of "seeing" a target from one epoch to the next is different since the range is changing. The brute force approach to solving this problem is to use either a "tree" analysis (Reference 2) or a Monte Carlo analysis. Because of the potentially large number of epochs, the "tree" analysis was discarded and a Monte Carlo simulation was employed instead. The program listing for this simulation is presented as Appendix 1. Briefly speaking, this simulation simply "flies" the threat aircraft toward BCAS and computes the probabilities. A fundamental assumption in this analysis is that the position of aircraft other than BCAS and the threat aircraft are statistically independent from one epoch to the next. Also,

the BCAS was assumed to have a fairly sophisticated degarbling capability. This is based on empirical data which indicates that there exist techniques which will provide degarbling values of g_1 = 80% and g_2 = 60%. It should be noted that the systems capability is very sensitive to the choice of degarbling values, and one should not assume that a BCAS using less sophisticated techniques will provide comparable performance.

Using these probabilities, 20,000 trials are then executed and the successful number of threat acquisition based on the L out of M rule are recorded. The probability of successful BCAS threat acquisition is then calculated from:

$$P_s = \frac{\text{Number of successes}}{\text{Total number of trials}} \tag{7}$$

APPLICATION TO MODE A DATA LINK

Assuming that two aircraft are BCAS equipped, it is possible for each aircraft to choose a maneuver given that they detect each other as a threat. A special Mode A code loaded into the transponder of each BCAS can then be used as the basis for coordination if each BCAS interrogates the other on Mode A. To analyze the effectiveness of a Mode A data link utilizing two separate codes to indicate maneuver intent (e.g., 7100 climb, 7200 dive) again equations 5, 6, and 7 are employed. In this case, however, the method for computing the number of successes in equation 7 is changed. Fundamentally, the criterion for success in this case is the successful reception by both BCAS aircraft in the conflict situation of each other's maneuver intent twice in a row and that the maneuvers are compatible. A default mode of posting the last maneuver chosen, even in the event that no coordination occurs, is included. The detailed flow chart of this algorithm is presented as Figure 4. In any event, a maneuver is selected and the number of successes is counted by considering the total number of displayed maneuvers which are compatible. It should also be noted that in this simulation the degarble probabilities were chosen to be unity since that would be the upper limit, if it were possible to construct a device to perfectly utilize the priori information concerning the codes of interest.

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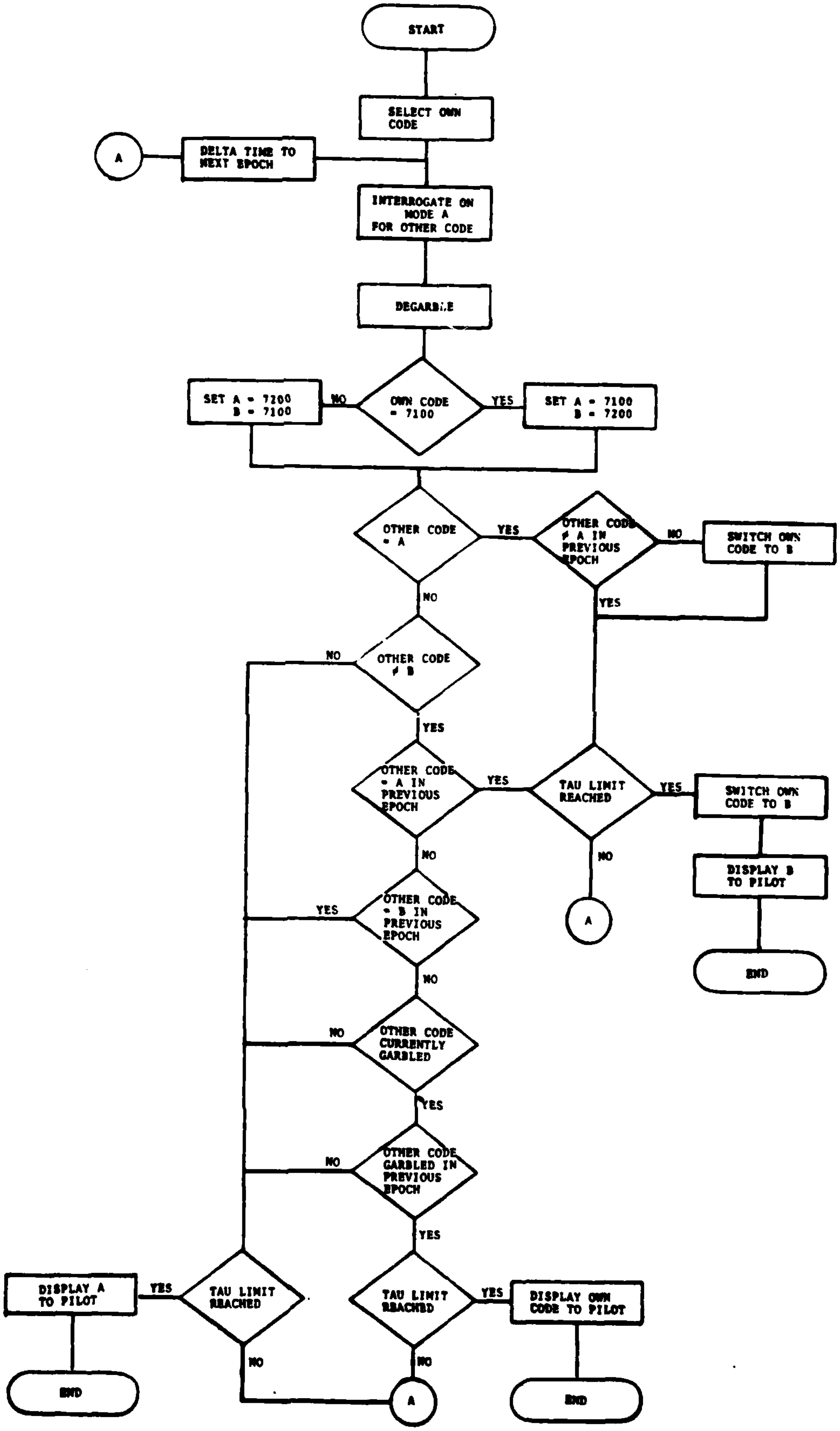

FIGURE 4 -- MODE A DATA LINK COORDINATION ALGORITHM

This is in contrast to the more standard but yet sophisticated degarbling techniques used without a priori information as in threat acquisition in which case values of $g_1 = 80\%$ and $g_2 = 60\%$ were used based on empirical data. The listing for this program is presented as Appendix 2.

RESULTS

Two system approaches have been studied using the above analysis. Neither of these approaches represents the FAA active BCAS described in the draft National Aviation Standard for Active BCAS. The first of these is based on Mode C acquisition of ATCRBS targets utilizing a 3 second epoch, 600 watt transmitter, -77 dBm receiver sensitivity, and a Mode A data link for the tie-breaker. Diversity antennas were assumed on all aircraft. In order to post a compatible collision avoidance command at 25 seconds, the problem starts at 59 seconds before collision and requires 3 out of 4 successful epochs to acquire the threat, initiate track and perform conflict detection and prediction. At 47 seconds Mode A data link coordination is initiated and proceeds for eight epochs (see Figure 5) requiring at least two consecutive epoch successes as described above. These acquisition and coordination parameters have been chosen to achieve the high reliability required for maneuver coordination given a collision situation between two BCAS aircraft. The results of these analyses are presented in Tables 1 and 2.

The second system analyzed differs from the first in that the epoch time is 1 second, a 500W transmitter is used, and a data link using the DABS message structure is employed for coordination (see Reference 3). Using the DABS data link

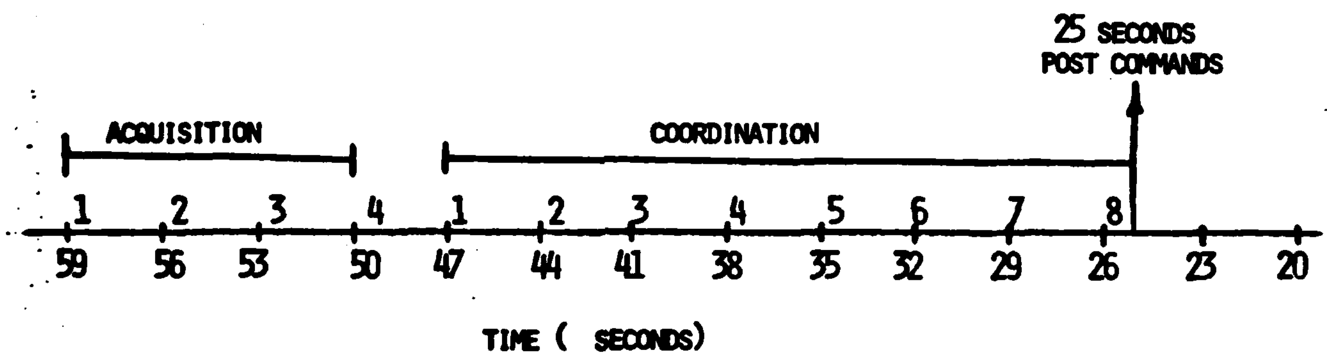

FIGURE 5

ATCRBS BCAS TIME LINE

TABLE #1

SYSTEM #1

ACQUISITION PROBABILITY

number of aircraft in 20 nm radius

closing speed (knots)	5	10	15	20	25	30
300	0.97935	0.89570	0.75095	0.57530	0.39905	0.25360
400	0.96485	0.81680	0.58670	0.35425	0.18100	0.08400
500	0.94360	0.71735	0.41715	0.18580	0.06895	0.02130
600	0.91660	0.61115	0.27175	0.08755	0.02150	0.00480
700	0.88400	0.49685	0.16140	0.03515	0.00635	0.00100
800	0.84040	0.38960	0.09405	0.01435	0.00195	0.00020
900	0.78525	0.29400	0.05210	0.00580	0.00065	0.00005
1000	0.72510	0.22015	0.02790	0.00245	0.00010	0.00005
1100	0.66205	0.16220	0.01550	0.00105	0.00005	0.00005
1200	0.59765	0.12460	0.01010	0.00060	0.00005	0.00005

TABLE #2

SYSTEM #1

MODE A COORDINATION

number of aircraft in 20 nm radius

closing speed (knots)	5	10	15	20	25	30
300	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
600	1.0000	1.0000	1.0000	0.9997	0.9970	0.9852
900	1.0000	1.0000	0.9993	0.9863	0.9454	0.8862
1200	1.0000	0.9998	0.9878	0.9310	0.8412	0.7405

allows for fast, highly reliable coordination at 26 seconds before collision thus allowing more time for threat acquisition. The 1 second update rate permits more attempts at threat acquisition and does not require the same high epoch success ratio (3/4) to establish track and perform the conflict detection and prediction functions.

For purposes of this analysis, the problem was started at 40 seconds before collision. Fifteen epochs were then allowed for threat acquisition with only 5 epoch successes required for track initiation, conflict detection and conflict prediction. One second was left for coordination of the evasive maneuver, ample time for the DABS link to perform its required function. The reliability of this link, (DABS to DABS) is about 99.5% for a single attempt at closure rates of 1200 knots, and 30 seconds before collision (Reference 1). About 5000 coordination attempts are possible with the DABS link in one second thus the probability of successful DABS coordination closely approximates unity. The results of the target acquisition probability analysis are presented as Table 3.

TABLE #3

SYSTEM #2

ACQUISITION PROBABILITY

number of aircraft in 20 nm. radius

closing speed (knots)	5	10	15	20	25	30
300	1.00000	1.00000	1.00000	1.00000	0.99985	0.99890
400	1.00000	1.00000	1.00000	0.99980	0.99720	0.98355
500	1.00000	1.00000	0.99985	0.99745	0.97745	0.89465
600	1.00000	1.00000	0.99930	0.98575	0.89750	0.68705
700	1.00000	0.99990	0.99640	0.94510	0.73495	0.41020
800	1.00000	0.99985	0.98735	0.85065	0.50510	0.19100
900	1.00000	0.99955	0.96435	0.70105	0.29205	0.07095
1000	1.00000	0.99845	0.91390	0.51390	0.14350	0.02065
1100	1.00000	0.99575	0.83200	0.34105	0.05955	0.00540
1200	1.00000	0.99040	0.72320	0.20405	0.02200	0.00140

CONCLUSION

It is obvious from the results presented that the system approach using a DABS data link for coordination is far superior in performance to that achievable in the ATCRBS only BCAS approach analyzed. In terminal areas, at densities of up to 0.02 aircraft/nm^2 threat acquisition probability are on the order of 97.75% at 25 seconds for head-on encounters (500 knots) and improve significantly for crossing or overtake encounters. At 20 seconds (i.e., a 5 second late alarm), the probability of acquisition improves to 99.98%. Coordination probabilities in all cases approach unity. In lower density en route airspace, say on the order of 0.008 aircraft/nm^2, a 99% probability of detection for 1200 knot closure rates is achievable at 25 seconds improving to 99.99% at 20 seconds.

In contrast to this approach, the ATCRBS only BCAS using Mode A data link has a 6% probability of acquisition at closure rates of 500 knots in a density of 0.02, a 42% probability at 500 knot closures in a density of 0.12 and a 12% probability

1200 knot closures in a density of 0.008. Further, the coordination probability in densities of 0.02 at terminal speeds is on the order of 99.7% for head-on encounters, but approaches DABS reliability in lesser densities even for 1200 knot closures. For example, at 1200 knot closures in a density of 0.008 a 99.98% reliability can be achieved. This, however, is of little help since the target cannot be acquired.

SUMMARY

A basic analysis tool has been developed which includes the principal BCAS design parameters, namely, transmitter power, receiver sensitivity, aircraft density, closure rate, degarble capability, and interrogation rate. This tool can be directly applied to the evaluation of alternative BCAS design concepts as well as for parametric design studies. Results of a comparison between a BCAS using a DABS data link and an ATCRBS only BCAS are presented leaving little doubt concerning the performance advantage offered by the inclusion of the DABS link for evasive maneuver coordination. Neither of the systems analyzed represents the Active BCAS described in the Draft National Aviation Standard for BCAS.

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2. Lipschutz, Seymour; Probability. New York: McGraw Hill Company, Inc., 1965.

3. U.S. National Aviation Standard for the Discrete Address Beacon System (DABS) Characteristics (Proposed in Federal Register, Vol. 43, No. 39, dated March 27, 1978).

APPENDIX 1

Program Listing for Threat Acquisition Simulation

*

```
C----- ----- ----- ----- ----- -----
C    TARGET ACQUISITION PROBABILITY
C    USING MONTE CARLO SIMULATION
C    TECHNIQUE
C       TWO AIRCRAFT...
C
C       DEL WEATHERS, SANDY BOCZENOWSKI -- AEM-200
C       FINAL VERSION   JAN 22, 1980
C----- ----- ----- ----- ----- -----
        INTEGER*2  IX,IY,EPOCH,TAQ,EPS,REPMIN
        INTEGER*2  CODE1,CODE2,PRIN11
        INTEGER*4 NUMBER
        REAL*4 P(30),MTL
C
        WRITE(1,100)
        CALL SETUP2 (T0,EPS,ETIM,REPMIN,G1,G2,MTL,TP)
C
C         -- CONTROL DENSITY OF AIRCRAFT --
C
        DO 25 N = 5,30,5
           WRITE(1,150)N
C
C          -- CONTROL RELATIVE SPEED --
          DO 20 IS = 300,1200,100
           S = FLOAT(IS)/3600.
C
            CALL PROB(T0,EPS,ETIM,G1,G2,TP,MTL,N,S,P)
            CALL SETUP0(NUMBER,ST,IX,IY)
C
C         -- CONTROL NUMBER OF TRIALS --
C
             DO 15 II = 1,NUMBER
C
              TAQ = 0
C
C        -- EPOCH CONTROL LOOP --
```

```
C
                  DO 10 EPOCH = 1,EPS
                     CALL CTRIAL (P,IX,IY,EPOCH,TAQ)
10        CONTINUE                          !EPOCH LOOP
C
C--- ----  TEST FOR SUCCESSFUL TARGET ACQUISITION
C
          IF (TAQ .GE. REPMIN) ST = ST + 1.
C
C
15        CONTINUE                     !TRIALS LOOP
          PST = ST/FLOAT(NUMBER)
          WRITE(1,160)IS,PST
C
20        CONTINUE                     !RELATIVE SPEED LOOP
25        CONTINUE                     !NO. OF AIRCRAFT LOOP
C
          STOP
100       FORMAT(/' -- TARGET ACQUISITION SIMULATION --'/)
150       FORMAT(3X,'NO. OF AC',I4,4X,'VEL.',5X,'PROB.')
155       FORMAT('  $,DISP1,DISP2 --> ',3(2X,I4))
160       FORMAT(18X,I6,3X,F9.5)
           END
C
C
          SUBROUTINE CTRIAL (P,IX,IY,EPOCH,TAQ)
          REAL*4 P(30)
          INTEGER*2 TAQ,EPOCH
          R = RAN(IX,IY)               !PROBABILITY OF GARBLE THIS EPOCH
          IF (R .LE. P(EPOCH)) TAQ = TAQ +1
          RETURN
          END
C
C
          SUBROUTINE SETUP0(NUMBER,ST,IX,IY)
          INTEGER*2 IX,IY
```

```
                                   *
        INTEGER*4 NUMBER
C
C       WRITE(1,110)
C         READ (1,112)NUMBER
        NUMBER=20000
C
        ST=0.              !INITIALIZE ACQUISITION COUNTER
        IX=0               !INITIALIZE RANDOM NUMBER SEED
        IY=0
C
         RETURN
110     FORMAT('$  NUMBER OF TRIALS -->')
114     FORMAT('$  DEBUG PRINTOUTS (Y=1/N=2) -->')
112     FORMAT(I4)
119     FORMAT(I8)
          END
C
C
C---------------------------------------------------------------------
C
C       SUBROUTINE TO GENERATE PROBABILITY OF MODE A COORDINATION
C       FOR UP TO 30 CONSECUTIVE EPOCHS
C
C       WRITTEN BY S. BOCZENOWSKI       12/17/79
C-----------------------------------------------------------------------
        SUBROUTINE PROB (T0,LIMIT,ETIM,G1,G2,TP,MTL,N,S,P)
        REAL*4 P(30),A(30),NC
        REAL*4 TP,FSPL,CL,MTL,LR,LM,PI
C
C----- CONSTANT VALUE 1/2 MESSAGE LENGTH
C
        DR = 20.3 / 6.08 *.5
        R  = 20.                  !RADIUS OF SURVEILLANCE
C
        TI = T0                   !INITIAL TAU
        NC = FLOAT (N -1)         !DO NOT COUNT TARGET AIRCRAFT
```

*

```
C
C----- COMPUTE PROBABILITY FOR EACH OF THE EPOCHS
C
        DO 111  K = 1,LIMIT
        PI = 3.14159265
        FSPL = 20.0 * ALOG10(4.0*PI*S*TI *6076.115 / 0.903)
        CL =6.0
        LM = TP - FSPL - CL - MTL
        LR = .5406214+ 0.1141024*LM-.0094811*(LM**2)+.0002628*(LM**3)
        IF(LR .GT. 1.0) LR = 1.0         !LIMIT TO ONE
C       WRITE(1,333)LR,LM,TP,FSPL,CL,MTL
333     FORMAT('  LR -->',6F10.4)
          A(K) = ((4.*S*DR*TI)/R**2) *LR
          P(K) = (1. - A(K))**NC
          P(K) = (P(K) + NC*A(K)*(1. - A(K))**(NC-1.)*G1)
         P(K)=P(K)+(G2/2.)*NC*(NC-1)*(A(K)**2)*((1-A(K))**(NC-2))
        P(K) = P(K) * LR
C         WRITE(1,900)K,TI,P(K)
900       FORMAT(' EPOCH ',I4,' TAU ',F9.0,' PROB. ',F9.4)
          TI = T0 - (ETIM * K)
111     CONTINUE
         RETURN
100     FORMAT('  ---ROUTINE PROB---')
998     FORMAT(X,A1)
          END
C----------------------------------------------------------------
C
C        REQUEST INPUT FOR VARIABLE CONDITIONS IN SIMULATION
C        INITIAL TAU, NO. OF EPOCHS, EPOCH DURATION, MINIMUM
C        NUMBER OF REPLIES TO DECLARE A SUCCESS
C        DEGARBLE PROBABILITY, TRANSMIT POWER, AND
C        MINIMUM TRIGGERING LEVEL OF RECEIVER
C
C       WRITTEN BY S.BOCZENOWSKI                    12/17/79
C
C-----------------------------------------------------------------
```

*

```
      SUBROUTINE SETUP2 (T0,EPS,ETIM,REPMIN,G1,G2,MTL,TP)
      INTEGER*2 EPS,REPMIN
      REAL*4 MTL
C
      WRITE(1,100)
C
      WRITE(1,908)            !INITIAL TIME
         READ(1,903) T0
      WRITE(1,916)            !NO. OF EPOCHS
         READ(1,901)EPS
      WRITE(1,917)            !TIME PER EPOCH
         READ(1,901)ITIM
            ETIM = FLOAT(ITIM)
      WRITE(1,918)                    !MINIMUM REPLIES FOR SUCCESS
         READ(1,901)REPMIN
      WRITE(1,920)            !PROB OF DEGARBLE
         READ(1,903)G1
      WRITE(1,922)            !DEGARBLE OF 2 OVERLAPS
         READ(1,903)G2
      WRITE(1,924)            !TRANSMIT POWER
         READ(1,903)TP
      WRITE(1,926)            !MINIMUM TRIGGERING LEVEL
          READ(1,903)MTL
      RETURN
C---------------------------------------------------------------------
C     CONSOLE I/O FORMATS
C---------------------------------------------------------------------
100   FORMAT('  ---ROUTINE SETUP2---')
901   FORMAT(I5)
903   FORMAT(F12.4)
906   FORMAT('$EPOCH INTERVAL IN SECONDS (R)--> ')
908   FORMAT('$INITIAL TIME (TAU IN SECONDS:R)--> ')
916   FORMAT('$NO. OF EPOCHS  (I) --> ')
917   FORMAT('$ EPOCH TIME IN SECONDS (I)--> ')
918   FORMAT('$NO. OF REPLIES FOR TARGET ACQUISITION (I) --> ')
920   FORMAT('$ DEGARBLE PROBABILITY 1ST OVERLAP (R)--> ')
```

```
922     FORMAT('$ DEGARBLE PROBABILITY 2ND OVERLAP (R) --> ')
924     FORMAT('$ TRANSMITTING POWER (R) --> ')
926     FORMAT('$ MINIMUM TRIGGERING LEVEL (R) --> ')
988     FORMAT('$PAGE OUTPUT(1) OR SCROLLING(2)--> ')
998     FORMAT(X,A1)
        END
*
```

APPENDIX 2

Program Listing for Mode A Data Link Simulation

*

```
C----- ----- ----- ----- ----- -----
C       MONTE CARLO SIMULATION
C       TWO AIRCRAFT...8 OR 9 EPOCHS
C       7100...FLY UP
C       7200...FLY DOWN
C       BOTH ARE BCAS EQUIPPED
C
C       DEL WEATHERS -- AEM-200
C       SANDY BOCZENOWSKI
C       FINAL VERSION JAN 22, 1980
C----- ----- ----- ----- ----- -----
        INTEGER*2  IX,IY,EPOCH
        INTEGER*2  OWN,POWN
        INTEGER*2  OTHER,POTH
        INTEGER*2  OWNG,POWNG
        INTEGER*2  OTHG,POTHG
        INTEGER*2  DISP1,DISP2,LIMIT
        INTEGER*2  CODE1,CODE2,PRIN11
        INTEGER*4 MATRIX(3,3),NUMBER
        REAL*4 P(9),DGP(4)
C
        DATA DGP /0.,.55,.85,1./
        WRITE(1,100)
        CALL SETUP2 (T0,LIMIT)
C
C       -- CONTROL DEGARBLE CAPABILITY --
C
C
         IDG=4
C         -- CONTROL NUMBER OF AIRCRAFT --
C
        DO 25 N = 5,30,5
C
C          -- CONTROL RELATIVE SPEED --
          DO 20 IS = 300,1200,300
           S = FLOAT(IS)/3600.
```

```
C
            CALL PROB(T0,LIMIT,IDG,N,S,P)
            CALL SETUP0(NUMBER,IX,IY,MATRIX)
C         -- CONTROL NUMBER OF TRIALS --
C
C
             DO 15 II = 1,NUMBER
        CALL SETUP1 (OWN,POWN,OTHER,POTH,OTHG,POTHG,CODE1,CODE2,
     +              OWNG,POWNG,DISP1,DISP2,IX,IY)
C
C        -- EPOCH CONTROL LOOP --
C
        DO 10 EPOCH = 1,LIMIT
C
C         -- OWN SYSTEM --
C
          IF(EPOCH .NE. 1)CODE2=OTHER
          CALL ALG (OWN,CODE2,POTH,OTHG,POTHG,EPOCH,P,
     +            IX,IY,DISP1,LIMIT)
C         IF(PRIN11 .EQ. 1)CALL PRINT1 (OWN,CODE2,POTH,OTHG,POTHG,
C     +                                EPOCH,DISP1)
          POTH = CODE2
C
C         -- OTHER SYSTEM --
C
          IF(EPOCH .NE. 1)GOTO 5
          CALL SETUP4(OTHER,IX,IY)
5         CODE1 = OWN
          CALL ALG (OTHER,CODE1,POWN,OWNG,POWNG,EPOCH,P,
     +            IX,IY,DISP2,LIMIT)
C         IF(PRIN11 .EQ. 1)CALL PRINT2 (OTHER,CODE1,POWN,OWNG,POWNG,
C     +                                EPOCH,DISP2)
          POWN = CODE1
C
10      CONTINUE
C
```

*

```
      IF(PRIN11 .EQ. 1)WRITE(1,155)II,DISP1,DISP2
      CALL TABLE(DISP1,DISP2,MATRIX)
C
15    CONTINUE                         !TRIALS LOOP
      WRITE(1,160)N,IS,DGP(IDG)
         CALL OUTPUT (MATRIX,NUMBER)
C
20    CONTINUE                         !RELATIVE SPEED LOOP
25    CONTINUE                         !NO. OF AIRCRAFT LOOP
30    CONTINUE                         !DEGARBLE CAPABILITY LOOP
C
C
      STOP
100   FORMAT(/' -- MANEUVER COORDINATION SIMULATION --'/)
155   FORMAT('  #,DISP1,DISP2 --> ',3(2X,I4))
160   FORMAT(' NO. OF AC',I4,' SPEED ',I6,' DEGARBLE ',F9.5)
       END
C
C
      SUBROUTINE OUTPUT(MATRIX,NUMBER)
      INTEGER*4 MATRIX(3,3),NUMBER
      REAL*4  RATIO
C
C     WRITE(1,110)
C     WRITE(1,112) MATRIX(1,1),MATRIX(1,2),MATRIX(1,3)
C     WRITE(1,112) MATRIX(2,1),MATRIX(2,2),MATRIX(2,3)
C     WRITE(1,112) MATRIX(3,1),MATRIX(3,2),MATRIX(3,3)
C
      RATIO = MATRIX(2,3)+MATRIX(3,2)
      RATIO = RATIO / FLOAT(NUMBER-1)
      RATIO = 100. * RATIO                    !CONVERT TO PERCENT
C
      WRITE(1,114)RATIO
      RETURN
110   FORMAT('   OUTPUT FROM SIMULATION '///)
112   FORMAT('  --  ',3(4X,I8))
```

*

```
114     FORMAT('   PERCENT OF COMPAT AND COMPLI MANEUVERS -->',F10.2//)
          END
C
C
        SUBROUTINE SETUP0 (NUMBER,IX,IY,MATRIX)
        INTEGER*2 IX,IY,LIMIT,PRIN11
        INTEGER*4 MATRIX(3,3),NUMBER
C
        DO 10 I=1,3
          DO 10 J=1,3
            MATRIX(I,J) = 0
10      CONTINUE
C
C       WRITE(1,110)
C       READ(1,119) NUMBER
        NUMBER=20000
C
        IX=0               !INITIALIZE RANDOM NUMBER SEED
        IY=0
C
         RETURN
110     FORMAT('$  NUMBER OF TRIALS -->')
114     FORMAT('$  DEBUG PRINTOUTS (Y=1/N=2) -->')
112     FORMAT(I4)
119     FORMAT(I8)
          END
C
C
        SUBROUTINE TABLE(D1,D2,MATRIX)
        INTEGER*2 D1,D2
        INTEGER*4  MATRIX(3,3)
C
        IF((D1 .EQ. 0) .AND. (D2 .EQ. 0))MATRIX(1,1)=MATRIX(1,1)+1
        IF((D1 .EQ. 7100) .AND. (D2 .EQ. 7100))
     +                 MATRIX(2,2) = MATRIX(2,2)+1
        IF((D1 .EQ. 7200) .AND. (D2 .EQ. 7200))
```

```
                                                 *
     +                MATRIX(3,3) = MATRIX(3,3)+1
        IF((D1 .EQ. 0) .AND. (D2 .EQ. 7100))
     +                MATRIX(1,2) = MATRIX(1,2)+1
        IF((D1 .EQ. 0) .AND. (D2 .EQ. 7200))
     +                MATRIX(1,3) = MATRIX(1,3)+1
        IF((D1 .EQ. 7100) .AND. (D2 .EQ. 0))
     +                MATRIX(2,1) = MATRIX(2,1)+1
        IF((D1 .EQ. 7100) .AND. (D2 .EQ. 7200))
     +                MATRIX(2,3) = MATRIX(2,3)+1
        IF((D1 .EQ. 7200) .AND. (D2 .EQ. 0))
     +                MATRIX(3,1) = MATRIX(3,1)+1
        IF((D1 .EQ. 7200) .AND. (D2 .EQ. 7100))
     +                MATRIX(3,2) = MATRIX(3,2)+1
C
        RETURN
         END
C
C
        SUBROUTINE SETUP4(OTHER,IX,IY)
        INTEGER*2  OTHER,IX,IY
        REAL*4 R
C
        OTHER=7100
          R=RAN(IX,IY)
         IF(R .GE. 0.5)OTHER=7200
        RETURN
         END
C
C
        SUBROUTINE SETUP1 (OWN,POWN,OTHER,POTH,OTHG,POTHG,CODE1,CODE2,
     +                OWNG,POWNG,DISP1,DISP2,IX,IY)
        INTEGER*2  OWN,POWN,OTHER,POTH,OTHG,POTHG
        INTEGER*2  OWNG,POWNG,DISP1,DISP2
        INTEGER*2  CODE1,CODE2,IX,IY
        REAL*4  R
C
```

```
C       WRITE(1,100)
C
C       R=RAN(IX,IY)    !PICK OWN CODE RANDOMLY
        OWN=7100
C       IF(R .LT. 0.5)OWN=7200
        CODE1=OWN
        POWN=1200        !PREVIOUS OWN CODE
        OTHER=1200       !OTHER'S INITIAL CODE
        POTH=1200        !OTHER'S PREVIOUS INITIAL CODE
        OTHG=0           !OTHER'S CURRENT GARBLE STATUS (Y=1/N=0)
        POTHG=0          !OTHER'S PREVIOUS GARBLE STATUS
        OWNG=0           !OWN'S CURRENT GARBLE STATUS
        POWNG=0          !OWN'S PREVIOUS GARBLE STATUS
        CODE2=1200
        DISP1=881
        DISP2=882
         RETURN
100     FORMAT('  ---ROUTINE SETUP1---')
          END
C
C
        SUBROUTINE ALG (CODE1,CODE2,PCODE,OG,PG,EPOCH,P,
     +                  IX,IY,DISP,LIMIT)
        INTEGER*2  CODE1,CODE2,PCODE,OG,PG,A,B
        INTEGER*2  EPOCH,IX,IY,DISP,LIMIT
        REAL*4     P(8),R
C
C       WRITE(1,100)
C
        IF(CODE1 .EQ. 7200)GOTO 50
          A = 7100
          B = 7200
          GOTO 60
50        A = 7200
          B = 7100
C
```

*

```
C        -- CHECK OTHER'S GARBLE STATUS
C
60       PG = OG
         R = RAN(IX,IY)                  !PROB OF GARBLE THIS EPOCH
         OG = 0          !ZERO OUT CURRENT GARBLE
         IF(R .LE. P(EPOCH)) GOTO 400    !LOOP ON NOT GARBLED
         OG = 1                          !SET GARBLED STATUS
         CODE2 = 1515            !MESS UP CODE2
C
C        -- CHECK CODE2'S CURRENT CODE
C
400      IF(CODE2 .EQ. A)GOTO 500
         IF(CODE2 .NE. B)GOTO 550
          GOTO 901
C
C        -- CHECK CODE2'S PREVIOUS CODE (RIGHT LOOP) --
500      IF(PCODE .NE. A) GOTO 902
          CODE1 = B              !SWITCH CODE
          GOTO 902
C
C        -- CHECK CODE2'S PREVIOUS CODE (CENTER LOOP) --
550      IF(PCODE .EQ. A)GOTO 902
         IF(PCODE .EQ. B)GOTO 901
C
C        -- CHECK IF CODE2 IS CURRENTLY GARBLED --
         IF(OG .EQ. 0)GOTO 901           !LOOP ON NOT GARBLED
C
C        -- CHECK IF CODE2 WAS GARBLED IN THE PREVIOUS EPOCH --
         IF(PG .EQ. 1)GOTO 903           !LOOP ON PREV GARBLED
          GOTO 901
C
C        -- TYPE 1 RETURN --
901      IF(EPOCH .EQ. LIMIT) DISP = A
          RETURN
C
C        -- TYPE 2 RETURN --
```

```
                              *
902     IF(EPOCH .EQ. LIMIT) GOTO 912
         RETURN
912      CODE1 = B
         DISP = B
          RETURN
C
C        -- TYPE 3 RETURN --
903     IF(EPOCH .EQ. LIMIT) DISP = CODE1
         RETURN
C
100     FORMAT('  ---ROUTINE ALG---')
          END
C
C
        SUBROUTINE PRINT1 (OWN,OTHER,POTH,OTHG,POTHG,EPOCH,DISP1)
        INTEGER*2  OWN,OTHER,POTH,OTHG,POTHG,EPOCH,DISP1
        WRITE(1,110)OWN,OTHER,POTH,OTHG,POTHG,EPOCH,DISP1
         RETURN
110     FORMAT('  OWN,OTHER,PREV,G,PG,EPOCH,DISP -->',7(1X,I4))
          END
C
C
        SUBROUTINE PRINT2 (OTHER,OWN,POWN,OWNG,POWNG,EPOCH,DISP2)
        INTEGER*2  OTHER,OWN,POWN,OWNG,POWNG,EPOCH,DISP2
        WRITE(1,110)OTHER,OWN,POWN,OWNG,POWNG,EPOCH,DISP2
         RETURN
110     FORMAT('  OTHER,OWN,PREV,G,PG,EPOCH,DISP -->',7(1X,I4)/)
         END
C------------------------------------------------------------------
C
C       SUBROUTINE TO GENERATE PROBABILITY OF MODE A COORDINATION
C       FOR 8 OR 9 CONSECUTIVE EPOCHS
C
C       WRITTEN BY S. BOCZENOWSKI       12/17/79
C--------------------------------------------------------------------
        SUBROUTINE PROB (T0,LIMIT,IDG,N,S,P)
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```
      REAL*4 P(9),DGP(4),A(9),NC
      REAL*4 TP,FSPL,CL,MTL,LR,LM,PI
      LOGICAL*1 CLEAR
      DATA DGP/0.,.55,.85,1./
      DATA CLEAR/'032/
C
C     WRITE(1,100)
C
C----- CONSTANT VALUE 1/2 MESSAGE LENGTH
C
      DR = 20.3 / 6.08 *.5
      R  = 20.                     !RADIUS OF SURVEILLANCE
C
      TI = T0                      !INITIAL TAU
      NC = FLOAT (N -1)            !DO NOT COUNT TARGET AIRCRAFT
C     IF(IPG .EQ. 1) WRITE(1,998)CLEAR
C
C
C
C----- COMPUTE PROBABILITIES FOR EACH OF THE EPOCHS
C
      DO 111  K = 1,LIMIT
      PI = 3.14159265
      FSPL = 20.0 * ALOG10(4.0*PI*S*TI *6076.115 / 0.903)
      TP = 57.78
      CL =6.0
      MTL = -77.0
      LM = TP - FSPL - CL - MTL
      LR = .5406214+ 0.1141024*LM-.0094811*(LM**2)+.0002628*(LM**3)
      IF(LR .GT. 1.0) LR = 1.0        !LIMIT TO ONE
C     WRITE(1,333)LR,LM,TP,FSPL,CL,MTL
333   FORMAT('  LR -->',6F10.4)
        A(K) = ((4.*S*DR*TI)/R**2) * LR
        P(K) = (1. - A(K))**NC
        P(K) = (P(K) + NC*A(K)*(1. - A(K))**(NC-1.)*DGP(IDG))
       P(K)=P(K)+0.50*NC*(NC-1)*(A(K)**2)*((1-A(K))**(NC-2))
```

*

```
      P(K)=P(K) * LR
C       WRITE(1,900)K,TI,P(K)
900     FORMAT(' EPOCH ',I4,' TAU ',F9.0,' PROB. ',F9.4)
        TI = T0 - (3. * K)
111   CONTINUE
       RETURN
100   FORMAT('  ---ROUTINE PROB---')
998   FORMAT(X,A1)
        END
C-----------------------------------------------------------------
C
C      REQUEST INPUTS FOR VARIABLE CONDITIONS
C     OF SIMULATION INITIAL TAU, NO. OF EPOCHS
C
C     WRITTEN BY S.BOCZENOWSKI                  12/17/79
C
C------------------------------------------------------------------
      SUBROUTINE SETUP2 (T0,LIMIT)
C
      WRITE(1,100)
C
      WRITE(1,908)             !INITIAL TIME
          READ(1,903) T0
      WRITE(1,916)             !NO. OF EPOCHS
          READ(1,901)LIMIT
          IF(LIMIT .GT. 9) LIMIT = 9
      RETURN
C-----------------------------------------------------------------------
C     CONSOLE I/O FORMATS
C------------------------------------------------------------------------
100   FORMAT('  ---ROUTINE SETUP2---')
900   FORMAT('$ENTER NO. OF AIRCRAFT (I)--> ')
901   FORMAT(I5)
902   FORMAT('$RADIUS OF SURVEILLANCE (R)--> ')
903   FORMAT(F12.4)
904   FORMAT('$RELATIVE SPEED IN KTS. (R)--> ')
```

```
906     FORMAT('$EPOCH INTERVAL IN SECONDS (R)--> ')
908     FORMAT('$INITIAL TIME (TAU IN SECONDS:R)--> ')
912     FORMAT('$DEGARBLE PROBABILITY (R)--> ')
914     FORMAT('$FRUIT PROBABILITY (R) --> ')
916     FORMAT('$NO. OF EPOCHS (8 0R 9) --> ')
988     FORMAT('$PAGE OUTPUT(1) OR SCROLLING(2)--> ')
998     FORMAT(X,A1)
        END
*
```

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